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In 1993, Neptune Technologies designed and fabricated two prototype array cables under NRL's support. Briefly, these two generic cables consisted of a monolay construction utilizing 18 singles and a twisted pair construction incorporating seven twisted pairs. Each conductor core was strengthened with an overbraid of Kevlar, then one core was jacketed with a braided sleeve of polyester which incorporated a fuzz type fairing, while the monocore incorporated an extruded jacket with a straked strum suppressor.

The essence of the new cables are small AWG#26 conductors insulated with a thin coating of Surlyn. These much smaller conductors are expected to provide a smaller cable with higher reliability./ See Neptune Report dated December 32, 1993, entitled "Prototype Cable Final Technical Report".

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NAVAL RESEARCH LABORATORY ARRAY CABLE QUALIFYING TEST PROGRAM

FINAL REPORT

SUBMITTED TO:

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CONTRACT #N00014-94-P-6911
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AUGUST 1, 1994

NAVAL RESEARCH LABORATORY CABLE QUALIFYING TEST PROGRAM

OBJECTIVE:

Develop a smaller, more reliable and cost effective array cable for NRL's general use.

BACKGROUND:

In 1993, Neptune Technologies designed and fabricated two prototype array cables under NRL's support. Briefly, these two generic cables consisted of a monolay construction utilizing 18 singles and a twisted pair construction incorporating seven twisted pairs. Each conductor core was strengthened with an overbraid of Kevlar, then one core was jacketed with a braided sleeve of polyester which incorporated a fuzz type fairing, while the monolay core incorporated an extruded jacket with a straked strum suppressor.

The essence of the new cables are small AWG#26 conductors insulated with a thin coating of Surlyn. These much smaller conductors are expected to provide a smaller cable with higher reliability. See Neptune Report dated December 31, 1993, entitled "Prototype Cable Final Technical Report".

DISCUSSION:

Several requirements must be met for these new small conductors and small diameter cables to be adopted as NRL's general array cable. The insulation on the conductors must provide insulation integrity under high water pressure over an extended period of time. Also, it is highly desirable that common molding materials such as polyurethane could be bonded to the insulation to increase realiability for connector attachment requirements.

In addition, these cables must qualify for mechanical strain in cyclic tension and bending similar to what they would encounter during life time useage. It is intended that these cables can endure repeated useage over time with high realiability to minimize the data acquisition costs.

Finally, it should be demonstrated that these cables can be procured at minimum cost, easily terminated, and quickly converted into highly realiable sensor arrays without undue skill or effort.

MECHANICAL TESTING:

An initial requirement was to specify and test a mechanical termination complete with installation procedures. This termination would develop the breaking strength of the cable, pass the conductor core through the load bearing fixture, not present undue compression loading to the conductor core and be easily applied with the ability to inspect the finished product. A modified Hood splice was selected utilizing longer helix angles

at ~~the~~ the throat of the eye and a special thimble. This would minimize compression loading on the unjacketed twisted pairs.

Once the procedure was documented and several test specimens prepared, then the termination and cable was qualified by the usual series of mechanical testing. The mechanical cable qualifying test was carried out utilizing NRL's cable test facility. (See termination procedures)

* ELONGATION AND BREAKING STRENGTH: Specimens 18' long were terminated with eye splices incorporating special thimbles. Each specimen was cyclic tensioned 10 times to 2500#, and then to break on the 11th cycle. The stress/strain curve was measured at approx. 25% of breaking strength and recorded. The average of the final breaks was adopted as the rated breaking strength. Conductor continuity was monitored and noted to break. Operational loading of these cables is recommended to be 25% or less of this established breaking strength.

Initially, three specimens were prepared by removing the cable jacket under the back splice. The average breaking strength for these three specimens was 9500#. Also, the conductors prematurely lost continuity in the area of the seizing at the thimble.

Three more specimens were prepared applying the backsplice directly over the cable jacket, i.e., not removing the jacket. The average breaking strength was 10,166#. Again, the conductors failed prematurely at the seizing site.

A third set of three specimens was then prepared which altered the helix rate of the back splice and loosened the seizing at the thimble. The average breaking strength was then 11,500# and the conductors maintained continuity to break. The average constructional stretch after 10 cycles to 2500# for these three specimens was 0.35% and the elestric stretch was 1.0%.

* CYCLIC TENSION, FATIGUE: Three each 18' samples with eye splices and special thimbles were cyclic tensioned between 0 and 2500#, 500 cycles each. Continuity was continuously measured. A water bath test was conducted after 500 cycles. The conductors were meggared at 500 volts to water. A minimum of 1000 megaohms of resistance to water was required.

Two samples were broken to measure the residual breaking strength. The third sample was subjected to additional cyclic tensioning to a total of 5,300 cycles. Insulation integrity and continuity was maintained in all specimens. The residual breaking strength for the first two specimens was 10,500# and 9.500#. The third specimen broke at 11,500#, indicating no degradation due to cyclic loading.

* CYCLIC BENDING: Three each 20' samples with eye splices and special thimbles ~~was~~ were terminated and cyclic bent around an 18" sheave at 2500# tension.

Sample #15 was cycled 1000 straight-bend-straight cycles without degradation to the continuity or insulation resistance. The residual straight breaking strength was 12,500#. Sample

#16 opened two conductors after 600 cycles. The residual breaking strength was 9,500# after 1,000 cycles.

Sample #17 was cycled 5,000 cycles before any electrical degradation was measured. The first conductor opened at approximately 6,000 cycles. The specimen was subjected to a total of 7,200 cycles and had a residual breaking strength of 12,000#.

All three specimens were meggared at 500 volts in water after bend cycles with no indication of degradation in their insulation integrity.

COMMENTS

All specimens broke in the back of the eye splice. Using a standard 3/8" heavy duty thimble and reeving the Kevlar around it in opposite directions forms a high stress area at the back of the thimble. This is aggravated by some slippage on the grip side causing a tension imbalance in the strands. However, the resulting breaking strength is very near the ultimate strength of the cable. The ease of application and reliability of the termination warrants its utilization.

ARRAY FABRICATION CONSIDERATION

Currently NRL utulizes AWG 22 stranded copper wire with 15 mils of EPC insulation on each conductor resulting in a 60 mil diameter. The twisted pair is uniquely color coded and is over-extruded with 10 mils of clear polyurethane. The result is a twisted pair 140 mils in diameter, expensive, and time

consuming to produce due to the multiplicity of production steps and colors. Also, the polyurethane jacket's purpose is to provide bedding for the pair, but this restricts water bath testing of the cable. In addition, due to polyurethane's high coefficient of friction, it restricts the conductors from sliding relative to each other when the cable is bent under tension.

Outer strength member Kevlar cables are particularly sensitive to conductor core buckling since they highly squeeze the core under tension and can put the conductors in the core in compression when bent under no tension. The cable can become crooked and wavy and lock up in bending. Ultimately, the conductors can experience excess compression loading and open or short to sea water.

Due to the large size of the cables and hydrophones, and the robustness of the conductors, single pin slip-on connectors are conveniently used. A major departure is required in this fundamental approach when switching to a conductor pair with only 18% of the volume of its predecessor. Polyurethane molding these small AWG 26 conductors directly to the hydrophone or connector leads is required.

To provide the high reliability of array insulation integrity it is highly desirable to bond directly to the primary insulation on the conductors thus avoiding the need for a secondary mechanical seal such as compression dams. Furthermore, the molding process must be simple, easy to perform, and highly repeatable. The resulting mold must be insensitive to time and water pressure.

Surlyn was selected as the candidate conductor insulation not only for its mechanical robustness but also for its bonding potential to a properly selected polyurethane.

Thus the most critical requirement for these small array cables to be accepted was the demonstration of a small practical polyurethane mold to interface these conductors to the sensors.

Several polyurethanes and cleaners were evaluated for this purpose. Both adhesion and water bath pressure testing were conducted. The currently used EPC insulated conductors were also included for comparative evaluation. The 3-M 2130 polyurethane was chosen due to its ease of handling and availability in a package that did not require evacuation.

The adhesion test consisted of potting in a 3/4" deep mold the EPC and Surlyn insulated wires cleaned with the four different cleaners, acetone, alcohol, MEK, and safety solvent.(Fig.1) The test was simply to try to pull the conductors out of the 3/4" engagement with the 3M 2130 polyurethane. In all cases, the EPC conductors pulled out while the Surlyn conductors broke. Reducing the engagement to 1/4" still held the Surlyn insulation indicating a very good bond.

Dissection of the molds revealed very good adhesion to the Surlyn insulated wires, independent of the cleaning material used. As expected, no adhesion was observed between the polyurethane and the EPC insulated wires.

A water pressure test was also conducted. (Fig.2) The Surlyn insulated conductors were soldered to MAW connectors. The solder joints were insulated by overmolding with 3M 2130

polyurethane. This models a practical array sensor attachment technique. After six months of exposure at 10,000 psi of water pressure, the molds and connectors were meggared at 500 volts to water. All provided over 1000 megaohms of insulation resistance to water.

Another test was to mold the ends of a Surlyn insulated wire in a cup of polyurethane (Fig.1) and subject the mold to 10,000 psi of water pressure for 30 days. After this period, the four specimens were meggared to water with over 1000 megaohms of resistance. This again implies a good bond to the Surlyn insulation, i.e., no water entered the stranded copper wire via a path between the Surlyn and the polyurethane.

A conductor identification test was conducted on the twisted pair cable. The test models the problem of entering the cable through the jacket along its length for conductor breakout for subsequent sensor attachment. Without positive color coding on each pair, there is some uncertainty whether the right pair has been located prior to cutting the pair. An inductive beeper was tested for this purpose (Fig.3). The technique is to inject a signal in the pair of interest and test the candidate pairs for the loudest beep as sensed with the induction amplifier. The units used were produced by Progressive Electronics.

The test clearly identified the pair carrying the signal on approximately 800' of the twisted pair array cable. This test confirms the cable design using only a keying color code on one pair with all the rest the same color. Thus the first step in identifying the pair of interest is to locate the key pair and

then count to the pair of interest. Any uncertainty can be eliminated then by confirmation with the beeper.

This process will eliminate the need of using many different colors of conductors which is currently the practice at NRL. Using only one color pair plus a key will reduce cost and cable lead time.

SUMMARY

The prototype array cable passed its qualifying tests very well. It maintained conductor continuity and insulation integrity while providing a residual breaking strength of 10,000# in tensile loading. Only two conductors opened in cyclic bending at approximately 600 flexure cycles in one specimen. This of course is much more that the average array cable will be subjected. ~~to.~~ More importantly, the conductors maintained insulation integrity throughout all tests, indicating the robustness of the Surlyn insulation.

Also, the arrays are easily made up by terminating this cable with a modified Hood splice, locating and breaking out the conductor paids with the aid of a "beeper" and molding the conductors to the sensor interface leads directly with an easy-to-use polyurethane.

The recommended maximum working load of this cable is 2,500 pounds tension, and a minimum bend diameter of 18". The expected constructional stretch is 0.35 percent and the elastic stretch is 1.0 percent in this load range.

RECOMMENDATIONS

The normal drag coefficient should be accurately measured on this cable for subsequent array deflection estimates. This can easily be done at the NSTL tow tank facily by directly measuring the tow force on a tensioned specimen as a function of tow speed.

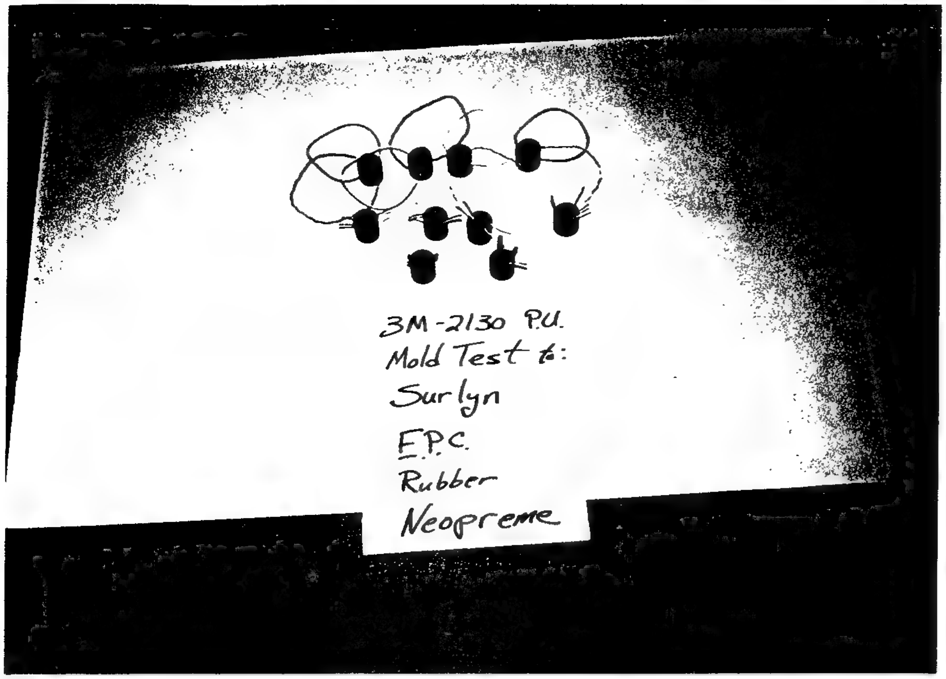
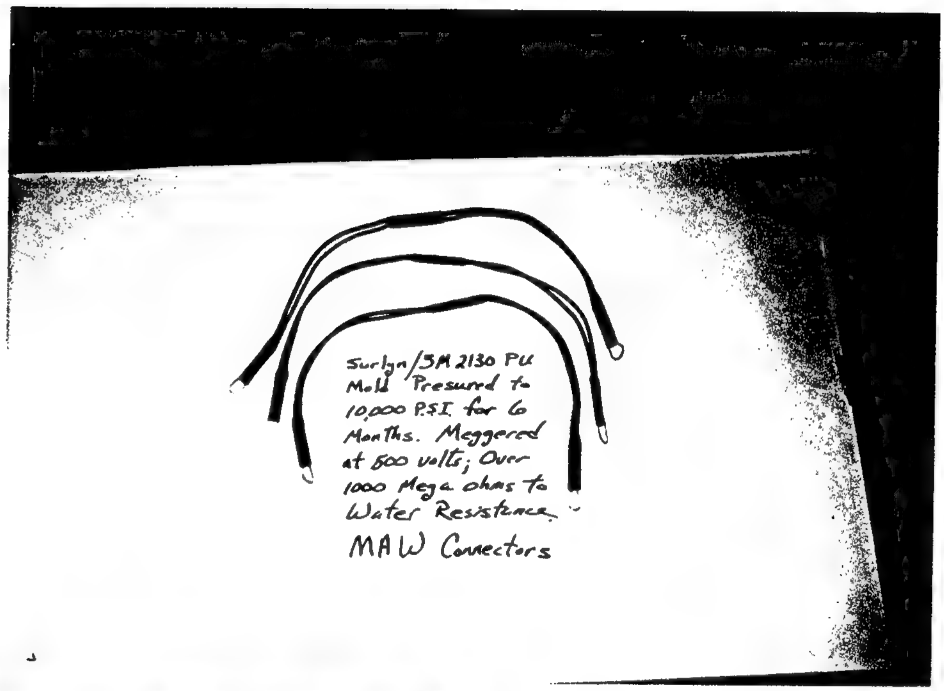


Figure 1.



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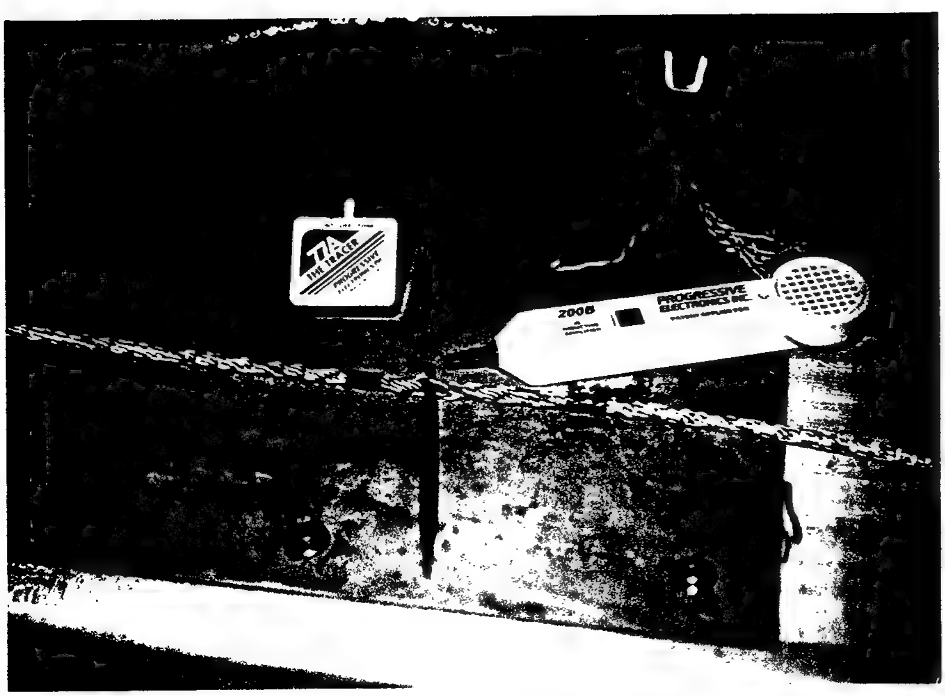


Figure 3.

EYE SPLICE TERMINATION INSTRUCTIONS FOR SMALL ELECTRICAL/MECHANICAL, KEVLAR REINFORCED CABLES

GENERAL

This instruction recommends a generic technique to terminate small braided Kevlar reinforced conductor cables with a fabric jacket sleeve. The prime features of the termination are to develop full strength, deliver the conductor core past the eye, minimize squeeze on the conductor core, fatigue resistance, and be applied with minimal skill while the finished termination can be easily inspected.

INSTRUCTIONS (Cable O.D. 0.5", core O.D. 0.3", rated strength 12,000#)

1. Remove 48" of cable sleeve.
2. Remove an additional 30" of fuzz fairing for a total end preparation of 78". (Fig.1)
3. Unbraid the 48" of exposed Kevlar into two equal groups, for example, ten dual strands in each group.
4. Thread the conductor core through the collar of a special thimble. Apply chafing protection to the conductor core as needed. (Fig.2)

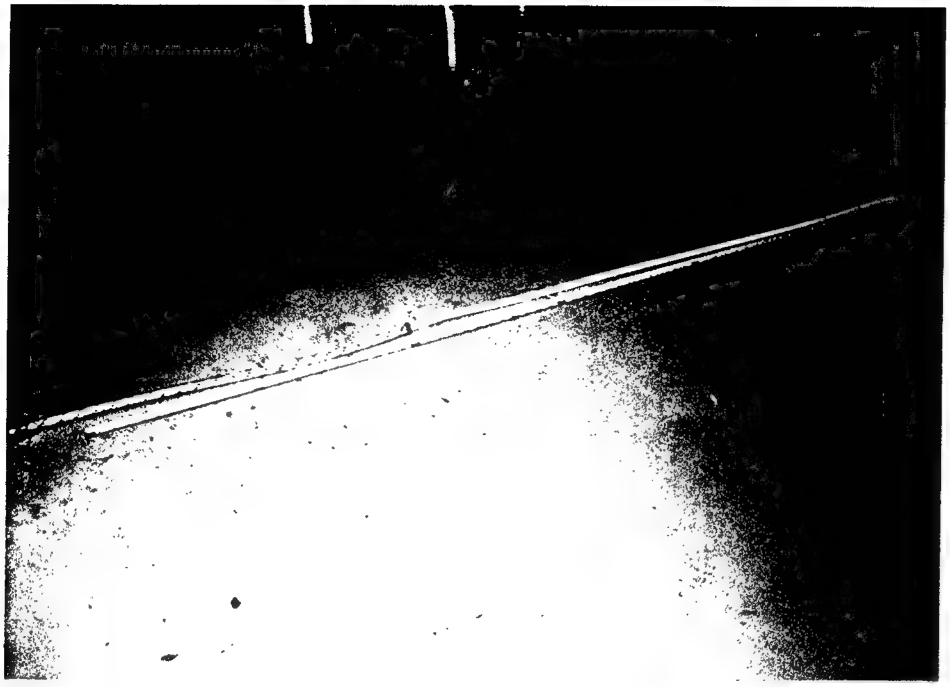


Figure 1.

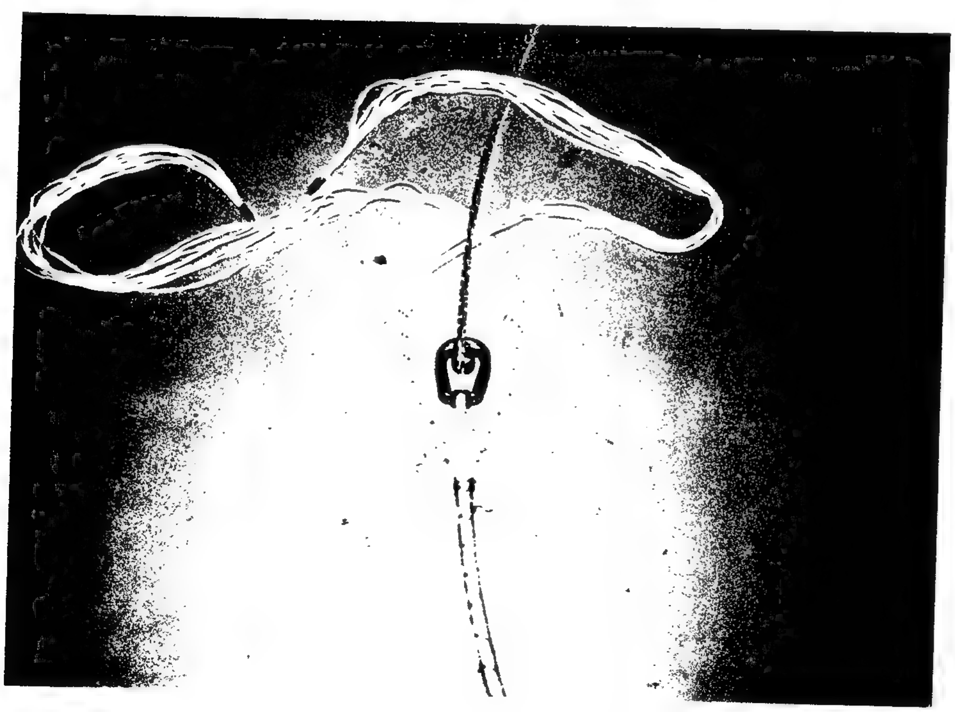


Figure 2.

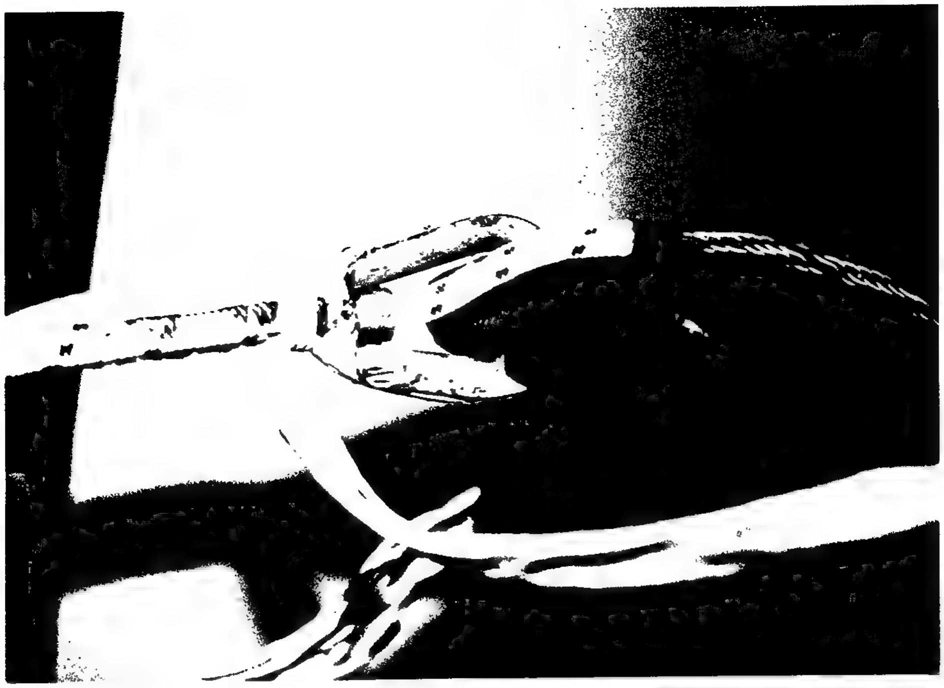
5. Wrap the two Kevlar groups in opposite directions around the thimble and seize loosely in place with small nylon seizing line. (Fig.3) NOTE: Take care to pull all the Kevlar strands tight and thus to equal length in each group. This process is best achieved with the thimble held in a vise and the cable held under modest tension, via an elastic stopper.

6. Now split each group into two equal legs, thus forming four legs to be utilized in forming the grip termination. (Fig.4)

7. Mark on the standing part of the cable (the 30" of sleeve without fairing) the leg crossing points starting at the thimble. These are 6", 10", 12", 14", 16", 18", 20", 22", 24", 25", 26", 27", and 28". The increase in helix is used to minimize the squeeze on the conductor core while transferring the legs from axial to near normal to the direction of cable tension.

8. Facing the thimble, from the direction of the cable, start with the upper left hand leg and wrap tightly around the cable, making one complete helix at each mark, i.e., the first helix length is 6", the next 4", the next seven are 2", and the last 4 are 1". (Fig.5) Apply a temporary tape at the end of the leg to hold it in place. Again, all strands should be initially pulled tight to insure equal length around the thimble and should be maintained tight with minimum strand crossings along the length of the grip to minimize slippage.

9. Repeat the same procedure with the upper right hand leg, but in the opposite direction. (Fig.6)



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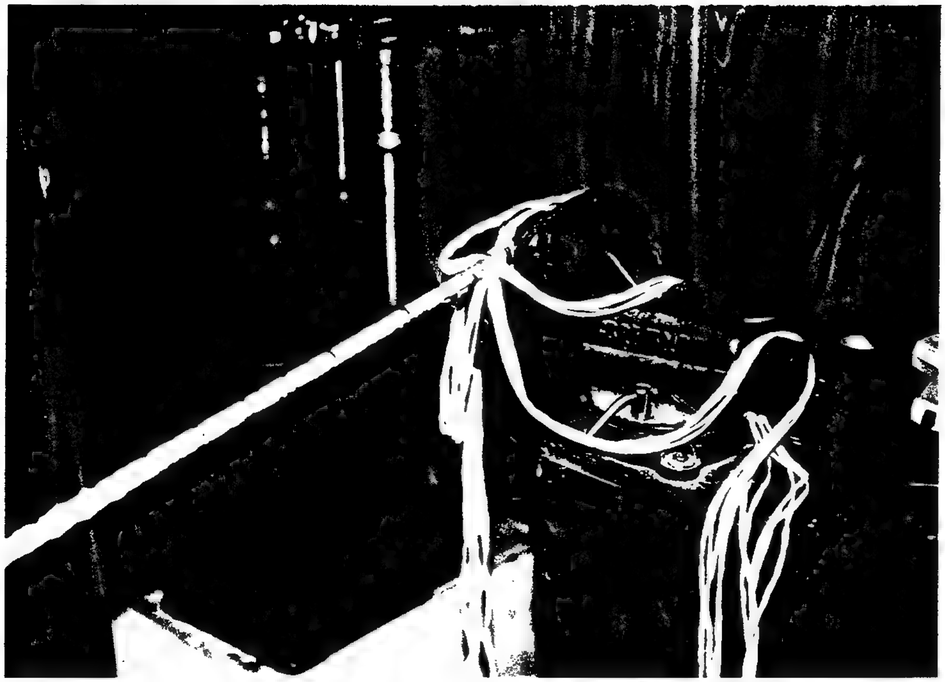

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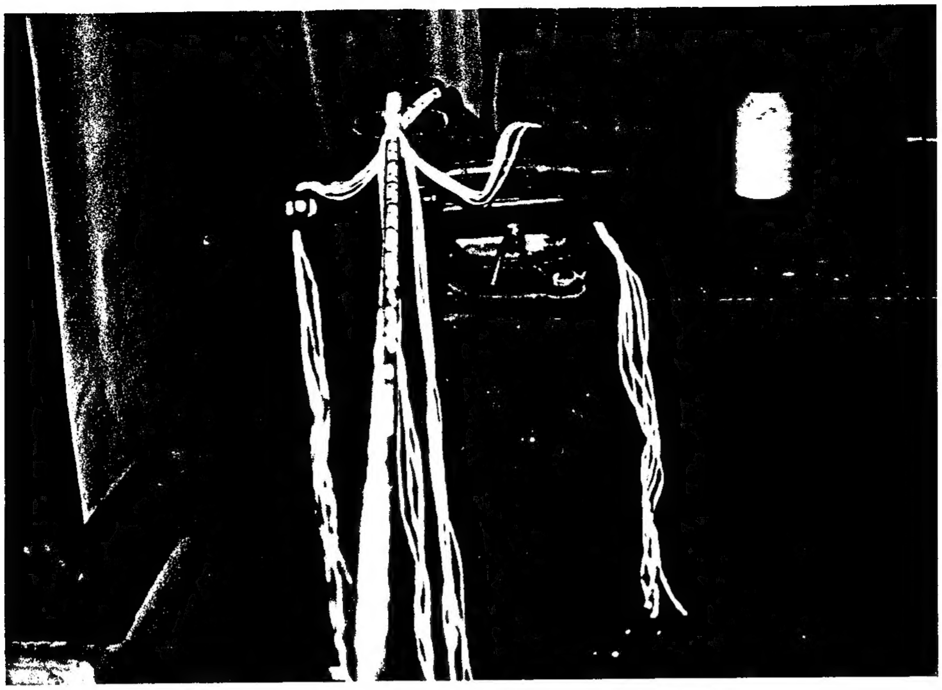


Figure 5.

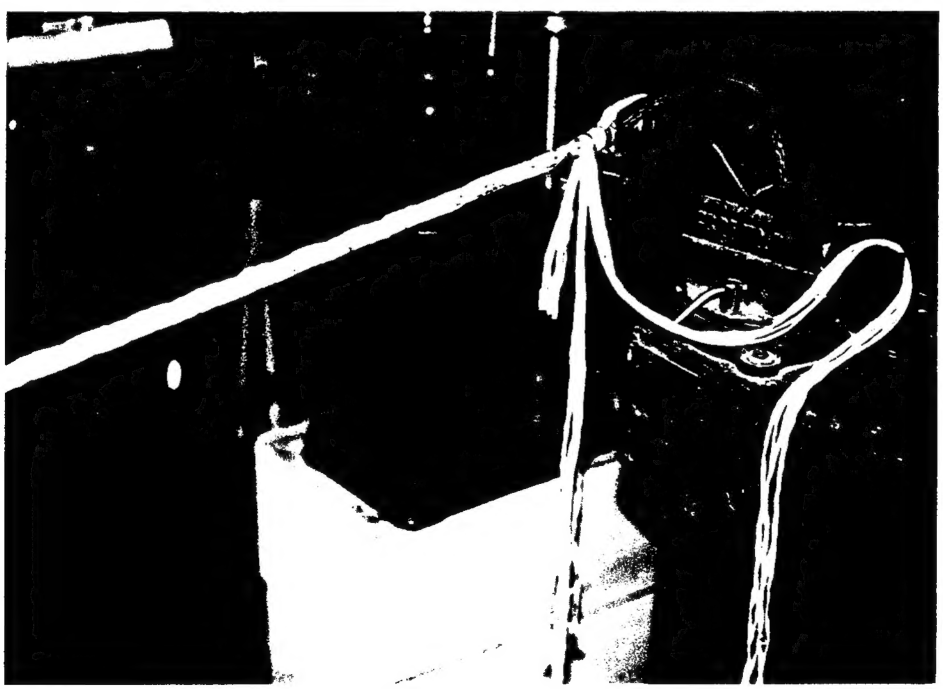


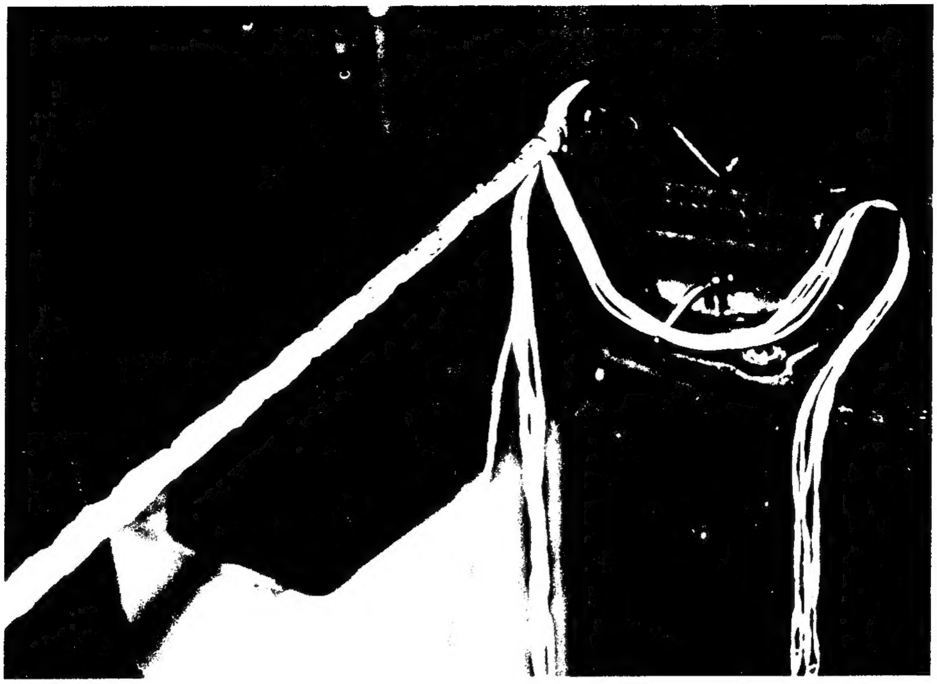
Figure 6.

10. Repeat, with the lower right hand leg, forming the same helix length but with the crossing on the opposite side of the cable. (Fig.7)

11. Finally, wrap the last leg, the lower left to complete the grip. (Fig.8)

12. Seize the tail end of the legs in two places with small nylon seizing line to set the grip. (Fig.9)

13. Overtape the grip to provide protection to the exposed Kevlar. (Fig.10)



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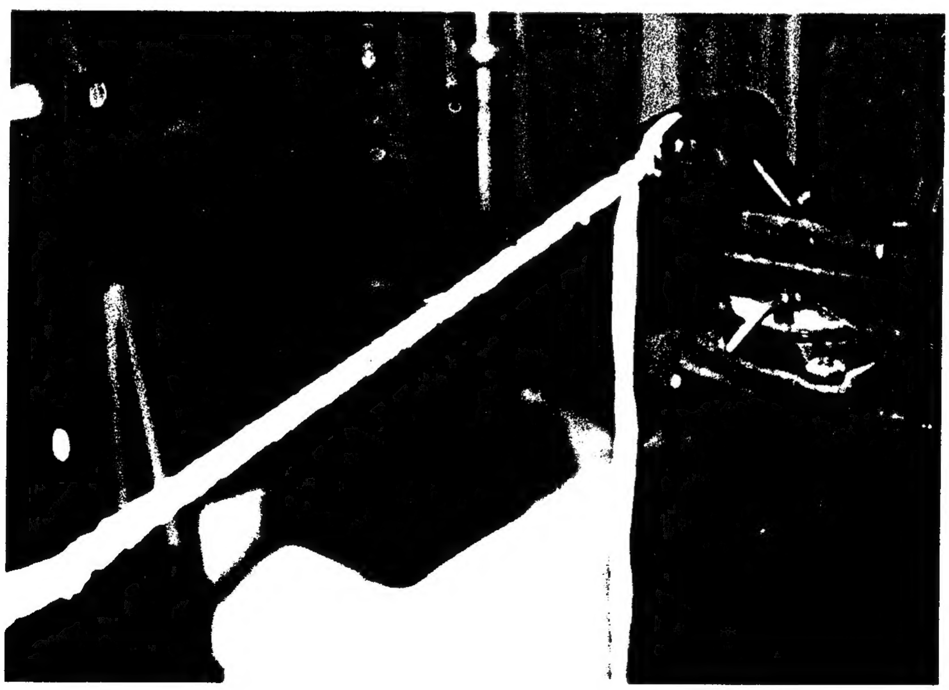

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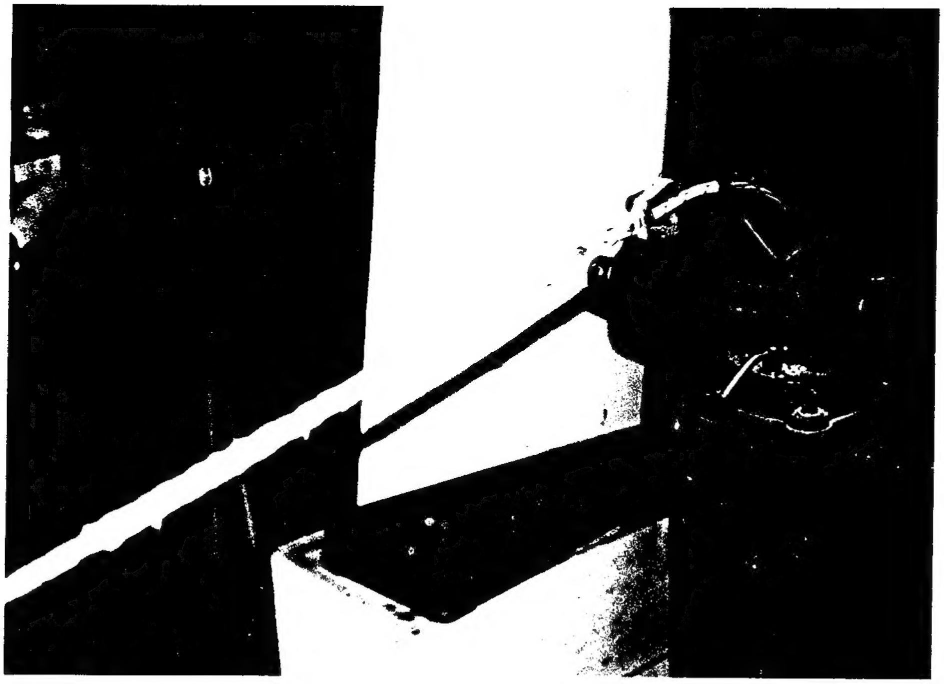

Figure 9.

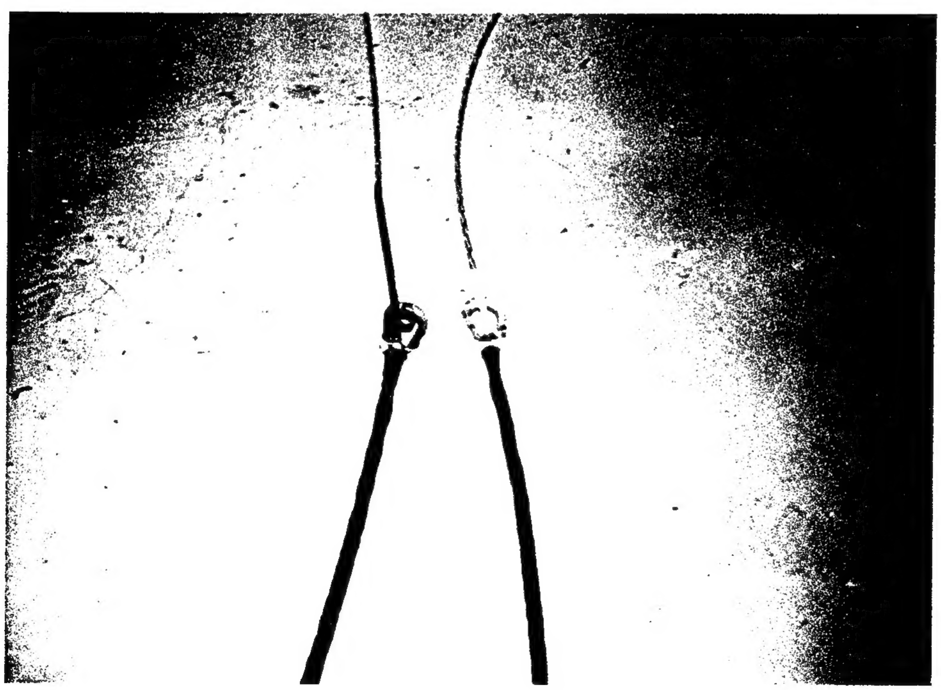

Figure 10.